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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Impact of glacier loss on annual basin water yields" *by* Evan Carnahan et al.

B. Schaefli (Referee)

bettina.schaefli@unil.ch

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General comments

This paper proposes to analyze the joint effect of glacier retreat and revegetation (due to climate warming) on the overall water balance of glacier-covered catchments for long term evolution (up to 500 years into the future). It does so with a simplified model whose possible outcomes are studied for different glacier retreat and revegetation scenarios, for two different climate types. The studied climates are continental and maritime climates, which are emulated by adjusting the glacier mass balance rate with elevation according to observed rates in these climates. No actual data is used in the presented study but the model parameters are selected in light of known /reasonable values for existing glacier catchments.

The idea of studying the possible evolution of catchment-scale water balance resulting

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from climate warming with a simplified model is appealing; it has the potential to explain in simple terms the possible outcomes (temporal increase of total basin runoff, overall decrease on the long run) without obscuring the involved mechanisms by a complex input-output model. In its current form, the results of the analysis are however hardly surprising and essentially say that "with more vegetation we get less runoff", which corresponds to an oversimplification of high alpine hydrology.

I am a hydrologist by training, with little knowledge in ice flow modelling. From my perspective, the used one-dimensional, depth- and width-integrated flow model, combined with different glacier mass balance rates seems to be a reasonable approach to generate different glacier retreat scenarios under climate warming. I find it, however, surprising that the authors choose an approach that does not allow to study the effect of the actual glacier shape (here a simple rectangle has been chosen) and that this aspect is not further discussed.

Regarding the hydrological side of the study, I have to admit that as I hydrologist I can only warn against the use of such oversimplified assumptions without sufficient discussion of the implications. To actually study the fundamental controls on the high alpine water balance, these fundamental controls and what we know thereof should be reviewed in detail before building a model.

My critic is the following: The parameterization of the effect of colonization is summarized by **two simple assumptions**: “First, we assume that the catchment becomes increasingly vegetated following deglaciation and that the type of vegetation only depends on time since deglaciation. Second, as areas of the catchment become colonized, the rate at which water is evapotranspired increases until reaching a maximum value representative of the climax vegetation state.” **While the first assumption seems reasonable** (some references would certainly be useful), the second assumption omits an important body of hydrological literature of the effect of vegetation on the water balance, and in particular the effect of forest (e.g. Andreassian, 2004). Forests show typically increased ET fluxes during younger states

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as compared to the climax state. Whether the typical vegetation succession to be expected in glacier catchments leads to a continuous ET increase with vegetation cover increase, remains to be demonstrated. I am not aware of literature on this topic (but it might well exist of course). In general the evolution of hydrological / geomorphological / pedological processes in moraines (and related runoff processes) can be assumed to be still largely unknown (see an ongoing project description here: http://gepris.dfg.de/gepris/projekt/318089487?language=en).

I do think that the approach is interesting. The hydrological assumptions should however be a bit more elaborate, including good references for glacier catchments and a detailed review of what we know today about the evolution of the water balance of newly vegetated areas in such catchments. If no sufficient literature can be found, possible hypotheses should be discussed in detail. This literature review should also include the important ongoing discussion what the effect of decreases in snow to rainfall ratios has on the catchment-scale water balance (Berghuijs et al., 20014). The relative decrease of snowfall might significantly contribute to the reduce of basin-scale runoff (add to the effect of vegetation). Similarly, a topic that should be discussed (even if not included in the analysis) is the interaction between glacier retreat and groundwater recharge. Not much is known so far about this topic but glacier retreat might change the relative amount of water that is available to vegetation in the non-glaciated part.

To summarize, to increase the value of this study, I suggest a good literature review of the impact of glacier retreat and the associated reduction of snow- to rainfall ratio on the water balance of high alpine catchments. Based on this, key processes and their synergy and possible unknowns should be identified. Based on this, the hydrological model can either be kept as is (but with more realistic future scenarios) or be refinde. At the very least, the hydrological simplifications should be more explicitly discussed.

Detail comments:

- Regarding the future ET fluxes, the reference to a paper that studied forest versus

crop / pasture across the globe in non-mountain environments (Zhang et al., 2001) is probably not adequate.

- The concept of **"runoff ratio"** is an engineering concept that was developed to separate precipitation into surface runoff and infiltration at the event scale (e.g. for the application of the so-called rational formula). What is used in this model is the **"annual runoff ratio"**, which is the ratio between total basin runoff and the total incoming precipitation. The total basin runoff is the sum of direct surface runoff and fast and slow subsurface runoff processes (and not the "runoff over an area of land"; the latter are the result of soil – vegetation interactions and groundwater recharge / release processes. This should be clear to avoid confusion for non-hydrologists.

- the conclusion should give clear indications about what should be explored on the hydrological side (not just the glaciological side)

References

Andreassian, V.: Waters and forests: from historical controversy to scientific debate, Journal of Hydrology, 291, 1-27, 10.1016/j.jhydrol.2003.12.015, 2004. Berghuijs, W. R., Woods, R. A., and Hrachowitz, M.: A precipitation shift from snow towards rain leads to a decrease in streamflow Nature Climate Change, 4, 583–586, 2014.

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